

## Ecological features of *Aconitum balfourii* (Bruhl) Muk. - an endangered medicinal plant in the northwest Himalaya

Bhuwendra Singh • R.S. Chauhan • Rajiv K. Vashistha • M. C. Nautiyal • P. Prasad

Received: 2010-11-29; Accepted: 2011-05-09  
© Northeast Forestry University and Springer-Verlag Berlin Heidelberg 2012

**Abstract:** *Aconitum balfourii* (Bruhl) Muk. (Ranunculaceae) is an endangered medicinal plant. Natural populations were surveyed in the northwest Himalaya for population estimation and evaluation of elite germplasm. Vegetation sampling of quadrats was conducted using the vertical belt transect method in areas supporting *A. balfourii*. Plant density and relative dominance of *A. balfourii* were low compared with other alpine species. Threat status was determined on a site-by-site basis as well as for entire western Himalaya. *A. balfourii* was generally classified as endangered on the basis of geographic distribution and critically endangered on the basis of abundance. We found the natural geographic distribution of *A. balfourii* to be diminishing due to habitat destruction. Immediate corrective management measures are needed for sustainable utilization and long-term conservation of the species in the wild.

**Keywords:** Endangered species; medicinal plant; soil analysis; population estimation; Ranunculaceae

### Introduction

*Aconitum* is a diverse genus of plants with tuberous roots belonging to the family Ranunculaceae, which is well represented in the Indian Himalayan region with 27 of nearly 300 species in the world. Thirteen species of *Aconitum* are reported to have medicinal properties (Chakravarty and Chakravarti 1954). Of these, five species are reported from Garhwal Himalaya. *A. balfourii* (Bruhl) Muk. is one of the important medicinal plants

categorized as an endangered species (Nautiyal et al. 2002). It is commonly known as Mitha Vish, or Bhangwa, and is distributed from 2800–4200 m. Tubers show different medicinal applications, including treatment of rheumatism, neuralgia, leprosy, paralysis, inflammation, analgesia, vermifuge, and pain and inflammation from gout, and disorders due to worms or microorganisms (Stapf 1905; Kirtikar and Basu 1935).

Tubers of *A. balfourii* contain a crystalline toxic alkaloid called pseudoaconitine (0.4–0.5%) and small quantities of aconitine, picroaconine, aconine, benzyl aconine, and hemonapelline (Anon. 1985). The demand for home and commercial use is met by harvest from the wild, which has caused depletion of wild populations. Information on taxonomy, general distribution, uses, ecophysiological characters, and phytochemical properties was reported by Stapf (1905), Kirtikar and Basu (1935), Gaur (1999), Naithani (1984), and Bahuguna et al. (2000). These researchers did not address the urgent need for information on (1) the status and trend of the species in nature, *i.e.* abundance and distribution, and (2) the population structure of plants in the wild. In this project we addressed these subjects to guide future sustainable utilization of the herb and its conservation in the wild. Quantitative inventories, more over, help identify species that are in different stages of vulnerability as well as the various factors that influence the existing vegetation in any region (Padalia et al. 2004; Parthasarathy 1999).

### Materials and Methods

#### Study area

We surveyed 16 study areas in the northwest Himalaya (Uttarakhand), India (Fig. 1) for occurrence of *A. balfourii*: Har-Ki-Dun (HKD), Yamunotri (YM) and Dayara (DR) in Uttarakashi district; Panwali Kantha (PK) in Tehri district; Pindari Glacier (PG) in Bageshwar district; Tungnath (TN), Kilpur (KP), Madhya Maheshwar (MD), and Kedarnath (KN) in Rudraprayag district; and The Valley of Flowers (VF), Hemkund (HK), Latakhark (LK), Dhudhatoli (DT), Rudranath (RN), Badani Bugiyal (BB),

Foundation project: This work was financially supported by the National Medicinal plant Board Govt. of India.

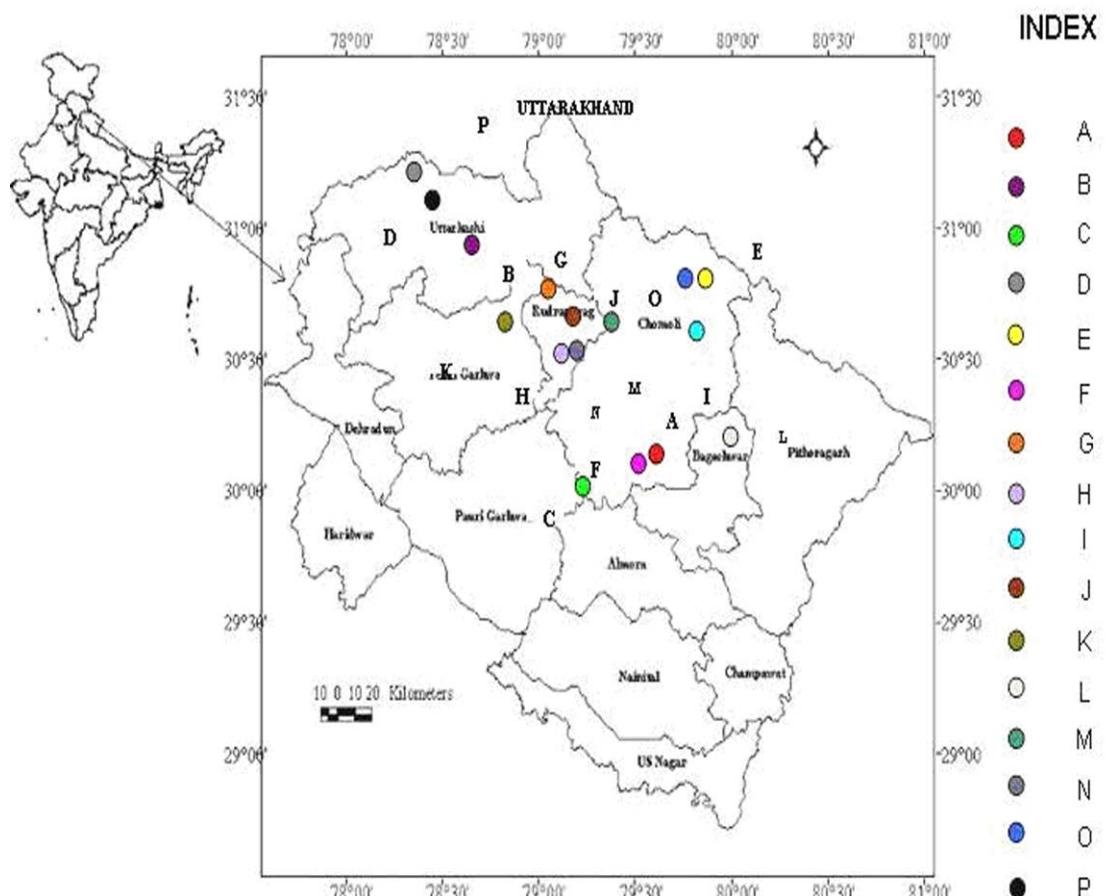
The online version is available at <http://www.springerlink.com>

Bhuwendra Singh • R.S. Chauhan • Rajiv K. Vashistha (✉)  
M. C. Nautiyal • P. Prasad  
High Altitude Plant Physiology Research Centre, PO Box - 14,  
Hemwati Nandan Bahuguna Garhwal Central University Srinagar  
Srinagar - 246174, Uttarakhand, India.  
E-mail: [rkvashistha78@gmail.com](mailto:rkvashistha78@gmail.com)

Responsible editor: Yu Lei

and Jhatal (JH) in Chamoli district of Uttarakhand state. These alpine sites are typically under heavy snow cover for six months during winter and 90%–95% of rainfall occurs during the monsoon season (July–August). The active growth period of *A. balfourii* is only six months annually (May–October). Abiotic pressures, e.g. high wind velocity, high ultraviolet radiation, and low

atmospheric oxygen levels were common at all study sites. All sites except The Valley of Flowers were exposed to similar anthropogenic impacts such as grazing, harvesting, and tourism. The Valley of Flowers was protected as national park where anthropogenic activities were restricted after 1982. The detailed description of each site is given in Table 1.



**Fig. 1** Map of study sites for *A. balfourii* (A-Badani Bugiyal, B-Dayara, C-Dhudhatoli, D-Har-Ki-Dun, E-Hemkund, F-Jhatal, G-Kedarnath, H-Kilpur, I-Latakhark, J-Madhyamaheshwar, K-Panwali Kantha, L-Pindari Glaceir, M-Rudranath, N-Tungnath, O-The Valley of Flowers, and P-Yamunotri).

## Methods

We analyzed vegetation at the same stands on selected sites for two consecutive years, 2008 and 2009. Data presented here are averaged over these two years. For threat category determination we established and marked quadrats measuring 100 m × 100 m at sites supporting *A. balfourii*. We sampled vegetation along vertical belt transects as described by Michael (1990). We calculated parameters including percentage frequency (%F), density (D, plant·m<sup>-2</sup>), and total basal cover (TBC, cm<sup>2</sup>·m<sup>-2</sup>) following Mishra (1968). Diversity indices (e.g.  $\alpha$  and  $\beta$ ) were calculated following Whittaker (1972) to quantify the diversity and the relative abundance of *A. balfourii*. Mean values of each quantita-

tive parameter for three stands per transect were used for further analyses. Considering the endangered status of the species in the Himalayan region, the extent of occurrence and population estimation was also studied on all sites. The status of the species was determined for all sampled regions on the basis of the occurrence of extant species and the population estimation based on IUCN (2001) guidelines. On the basis of extensive field visit, all possible populations of *A. balfourii* were identified, and the population density of the species was measured to assess the number of mature individuals in each stand and site to determine the threat categories for *A. balfourii*. We categorized status separately for each natural site as well as for the entire northwest Himalaya as a single unit.

Soils were sampled at the study sites from July to September

each year. Soils were sampled at depths of 0–10 cm and 10–20 cm. The samples were brought to the laboratory in tightly packed polythene bags and were air dried at room temperature. The samples were analyzed for chemical attributes *viz.*, pH (Goel and Trivedi 1992), organic carbon (OC) (Okalebo et al. 1993), soil

organic matter (SOM) (Walkley and Black 1934), total nitrogen (TN) (Allen 1974), exchangeable potassium (EK) (Jackson, 1958) and available phosphorus (AP) (Olsen et al. 1954). The data were statistically analyzed using simple correlation (Karl Pearson's) between soil parameters and plant density.

**Table 1.** Sites characteristic of the selected populations of *A. balfourii*.

Populations	Altitude (msl)	Latitude N	Longitude E	Habitats	Associated species	Dominant associate
BB	3 309	30°12'464"	79°39'762"	Moist shady sub-alpine slopes under canopy of <i>Rhododendron</i> scrub.	13	<i>Swertia speciosa</i>
DR	3 350	30°50'112"	78°33'984"	Moist shady sub-alpine slopes under canopy of <i>Taxus bacata</i> .	12	<i>Fragaria</i> sp.
DT	3 000	30°04'640"	79°11'918"	Moist shady sub-alpine slopes under canopy of <i>Quercus</i> sp.	16	<i>Fragaria</i> sp.
HKD	3 100	31°04'009"	78°17'426"	Moist shady sub-alpine slopes under canopy of <i>Quercus</i> sp.	11	<i>Thalictrum</i> sp.
HK	3 634	30°42'254"	79°36'543"	Moist shady Open meadow	8	<i>Polygonum</i> sp.
JH	3 639	30°11'644"	79°32'504"	Moist shady places	8	<i>Epilobium</i> sp.
KN	3 985	30°44'938"	79°03'578"	Moist shady Open meadow	4	<i>Potentilla atrosanguinea</i>
KP	3 230	30°30'651"	79°13'507"	Moist shady sub-alpine slopes under canopy of <i>Quercus</i> sp.	10	<i>Indigofera</i> sp.
LK	3 476	30°31'379"	79°46'350"	Moist shady sub-alpine slopes under canopy of <i>Rhododendron</i> scrub.	15	<i>Polygonum alpinum</i>
MD	4 003	30°39'022"	79°14'826"	Moist shady Open meadow	7	<i>Caltha</i> sp.
PK	3 120	30°34'798"	78°52'634"	Moist shady sub-alpine slopes under canopy of <i>Quercus</i> sp.	18	<i>Polygonum</i> sp.
PG	3 546	30°12'597"	80°00'332"	Moist shady places	5	<i>Senecio</i> sp.
RN	3 453	30°31'152"	79°18'901"	Moist shady sub-alpine slopes under canopy of <i>Rhododendron</i> scrub.	21	<i>Caltha paultris</i> .
TN	3 550	30°30'263"	79°13'593"	Moist shady sub-alpine slopes under canopy of <i>Rhododendron</i> scrub.	18	<i>Potentilla atrosanguinea</i>
VF	3 364	30°43'467"	79°35'887"	Moist shady Open meadow	12	Fern
YM	3 200	30°59'917"	78°27'806"	Moist shady sub-alpine slopes under canopy of <i>Quercus</i> sp.	10	<i>Senecio</i> sp.

BB--- Badani Bugiyal, DR--- Dayara, DT, Dhudhatoli, HKD--- Har-Ki-Dun, HK--- Hemkund, JH--- Jhatal, KN--- Kedarnath, KP--- Kilpur, LK--- Latakhark, MD--- Madhya Maheshwar, PK--- Panwali Kantha, PG--- Pindari Glacier, RN--- Rudranath, TN--- Tungnath, VF--- The Valley of Flowers, YM--- Yamunotri.

Abbreviations' explanation is same as the Table 2, 3, and 4.

## Results

Moist shady slopes under a canopy of *Rhododendron* shrub were the major habitats of *A. balfourii* (Table 1). Species richness at locations supporting *A. balfourii* was low at all sites but highest (21) at RN population and lowest (4) at KN. Plant density was highest (140.60 plant·m<sup>-2</sup>) at DT and lowest (31.0 plant·m<sup>-2</sup>) at YM. Community TBC was highest (47.16 cm<sup>2</sup>·m<sup>-2</sup>) at KN and lowest (7.42 cm<sup>2</sup>·m<sup>-2</sup>) at KP.  $\beta$  diversity was highest (2.50) at RN and lowest (1.11) at PG, where there was a high rate of change in species occurrence (Table 2). Dominant associates of *A. balfourii* were *Fragaria nubicola*, *Polygonum* spp., and *Senecio* spp. at most sites (Table 1). 100% percent frequency was recorded at BB, DT, HKD, HK, JH, KP, LK, MD, PG and YM. Percent frequency was 50 to 70% at other sites. TBC was highest (11.22 cm<sup>2</sup>·m<sup>-2</sup>) at BB and lowest (0.56 cm<sup>2</sup>·m<sup>-2</sup>) at TN. Among different populations, IVI was ranged between 7.09 and 83.85. Percentage of *A. balfourii* on the basis of IVI ranged from 2.36%–27.95% (Table 3). Relative density of *A. balfourii* was very low at TN (1.23%), VF (1.59%), RN (2.04%), and DT (2.84%), but peaked (23.67%) at BB. Relative dominance of *A. balfourii* was highest (51.17%) at BB and lowest (1.44%) at TN. Distribution of *A. balfourii* at most sites was random. A maximum of 3 pockets at DR and RN, and a minimum of 1 pocket at KP were identified as *A. balfourii* populations. Peak abundance

of 411 mature plants of *A. balfourii* was recorded at DR followed by 396 at BB. Minimum abundance of 87 mature plants was recorded at PG. Geographic distribution and population size are the main criteria used to assign threat categories based on population reduction and probability of extinction (IUCN 2001). Based on geographic distribution, we found *A. balfourii* to be endangered at most sites except KP. Based on abundance of mature plants, *A. balfourii* we considered *A. balfourii* to be endangered at BB, DR, HK, LK and RN and critically endangered at other sites (Table 4).

Soil at *A. balfourii* sites were generally sandy or silty loams, residues of metamorphic crystalline rocks, and were dark brown to dark gray or black (on moist boulder habitat). Soil pH values ranged between 4.62 and 5.59, organic carbon ranged between 1.07 and 2.78%, soil organic matter (SOM) ranged between 1.85% and 4.80%, total nitrogen ranged between 0.65% and 1.35%, exchangeable potassium (EK) between 0.03% and 0.079% and available phosphorus (AP) between 0.016% and 0.028% at depths of 0–10 cm (Fig. 2A). Soil pH value ranges between 3.78 and 5.20, organic carbon ranged between 0.81% and 1.42%, soil organic matter (SOM) ranged between 1.40% and 2.44%, total nitrogen ranged between 0.28% and 0.79%, exchangeable potassium (EK) between 0.037% and 0.086% and available phosphorus (AP) between 0.013% and 0.032% at 10–20 cm depths (Fig. 2B).

**Table 2. Plant density, total basal cover, diversity, and dominance of *A. balfourii* Garhwal Himalaya**

Sites	Plant density	Community TBC	$\alpha$ diversity	$\beta$ diversity
BB	101.80	21.92	14	1.26
DR	47.77	19.93	13	2.11
DT	140.60	11.69	17	1.54
HKD	67.90	11.21	12	1.12
HK	82.30	27.70	9	1.23
JH	77.30	23.98	9	1.15
KN	38	47.16	4	1.42
KP	55.33	7.42	11	1.26
LK	62.3	15.45	16	1.73
MD	89.6	29.14	8	1.17
PG	42.00	22.09	6	1.11
RN	73.4	37.27	21	2.50
TN	97.5	39.20	19	1.68
VF	81.80	18.11	13	1.42
YM	31.00	9.95	11	1.66

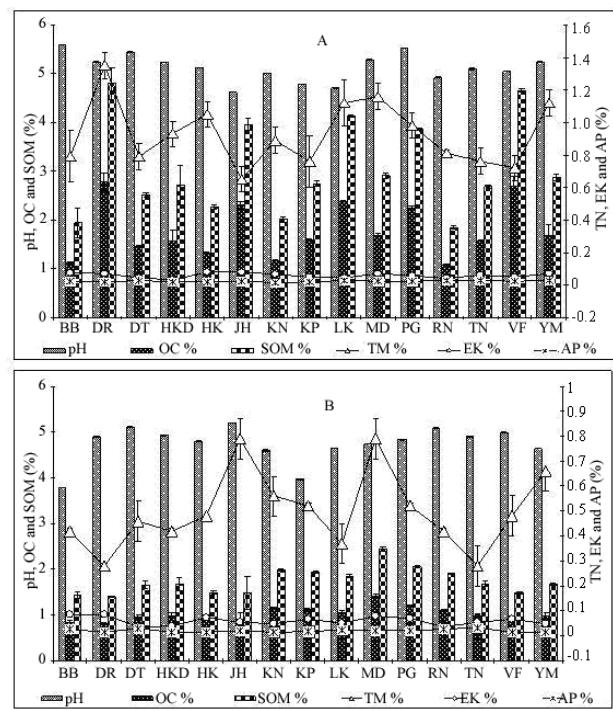
**Table 3. Ecological parameters of different populations of *A. balfourii***

Populations	Frequency (%)	Density (plant·m <sup>-2</sup> )	TBC (cm <sup>2</sup> ·m <sup>-2</sup> )	IVI	Share (%)	A/F ratio
BB	100	24.10	11.22	83.85	27.95	0.24
DR	92.31	7.92	3.72	50.27	16.75	0.09
DT	100	4	0.72	18.12	6.04	0.04
HKD	100	4.6	2.67	39.95	13.31	0.05
HK	100	2.8	1.98	24.26	8.08	0.03
JH	100	7.6	7.09	52.22	17.40	0.08
KN	60	1.6	0.75	27.23	9.07	0.04
KP	100	4.50	2.38	51.67	17.22	0.05
LK	100	7.2	4.48	51.40	17.13	0.07
MD	100	18.4	8.65	64.92	21.63	0.18
PG	100	1.4	0.78	25.36	8.45	0.01
RN	70	1.5	0.71	12.07	4.02	0.03
TN	50	1.2	0.56	7.09	2.36	0.05
VF	50	1.3	0.65	10.75	3.58	0.05
YM	100	2	1.11	33.22	11.07	0.02

**Table 4. Determination of threat status of *A. balfourii* in Garhwal Himalaya**

Populations	Relative density	Relative dominance	Extent of occurrence (Location No.)	Population estimation (Mature individuals)	Status (IUCN, 2001)
BB	23.67	51.17	2	396	E*, E**
DR	16.59	18.68	3	411	E*, E**
DT	2.84	6.19	2	95	E*, CE**
HKD	6.77	23.83	2	162	E*, CE**
HK	3.40	7.16	2	265	E*, E**
JH	9.83	29.56	2	249	E*, CE**
KN	4.21	1.59	2	173	E*, CE**
KP	8.13	32.00	1	127	CE*, CE**
LK	11.56	28.97	2	330	E*, E**
MD	20.54	29.68	2	203	E*, CE**
PG	3.33	3.51	2	87	E*, CE**
RN	2.04	1.89	3	319	E*, E**
TN	1.23	1.44	2	89	E*, CE**
VF	1.59	3.61	2	144	E*, CE**
YM	6.45	11.14	2	93	E*, CE**

\*Based on extent of occurrence; \*\*Population estimation.

**Fig. 2 Soil characteristics of *A. balfourii* populations: A (0–10 cm) and B (10–20 cm) depth**

## Discussion

Floristic inventory, survey and diversity studies help us to understand the species composition and diversity status of forests (Gordon and Newton 2006). Species richness measures provide an easily comprehensible expression of diversity. Whittaker (1972) defined  $\beta$  diversity as the ‘extent of species replacement or biotic change along environmental gradients’. Whittaker (1972) also established the importance of identifying  $\beta$  and  $\alpha$  diversity as components of overall plant diversity. Values of  $\beta$  diversity can be used to compare the habitat diversity of different study sites,  $\beta$  and  $\alpha$  diversity together can measure the overall diversity or biotic heterogeneity of an area (Wilson and Shmida 1984). Species diversity is affected by long term factors like community stability and evolutionary time as the heterogeneity of micro and macro environments impact the diversification of different communities (Verma et al. 2004). Variations in frequency can be ascribed to diverse soil conditions, seed dispersal mechanisms, grazing and other biotic factors as reported by Semwal (2006). Grazing can be the prime factor which governs vegetation structure and plant species occurrence, as reported by Sundriyal and Joshi (1991), Rikhar et al. (1993), Nautiyal (1996), and Rawat (2009). Density of a species provides an index to competition between individuals of the species. Higher densities can cause greater competitive stresses, leading to poor growth and lower reproductive capacity. We recorded *A. balfourii* at low densities (1.2–24.10 individual·m<sup>-2</sup>) and high (100%) frequencies. One potential explanation could be extensive harvesting from wild populations. Plants were typically uprooted arbitrarily, accounting for the low recorded densities.

Removal of the entire plant before seed maturation reduces the possibility of seed development for future regeneration (Sheldon et al. 1997). Importance value index (IVI) of the species represents the ecological success of any species in a community as a single value. This single value provides complete picture of sociological structure of a species, because the frequency provides information about the dispersal of a species in an area, density gives numerical strength of the species and dominance represents the basal area. Overall, IVI gives an excellent idea about varying environmental factors (Odum 2005).

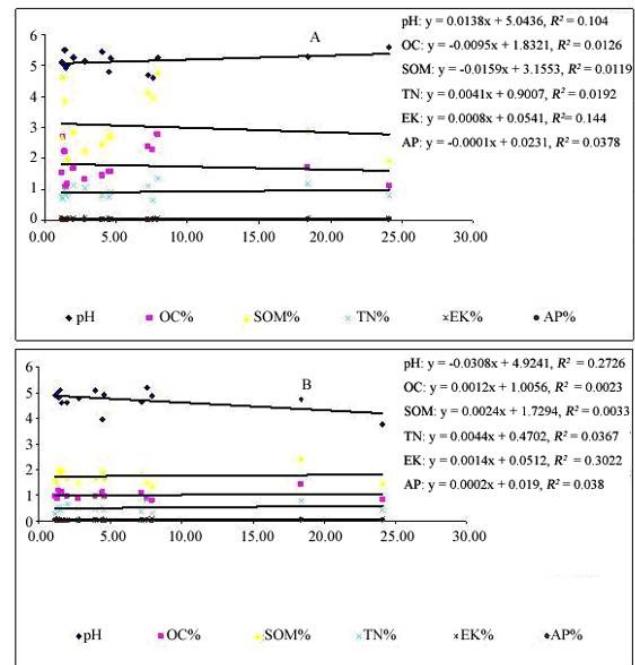
Ved et al. (2003) assigned vulnerable status for this species in Uttarakhand as well as at the global level. We assessed *A. balfourii* as endangered on the basis of geographic distribution and critically endangered on the basis of population estimation i.e. numbers of mature individuals. Erosion of diversity in natural plant populations in the Himalayan region during the recent past is not uncommon and has been attributed to irresponsible exploitation for the extraction of drugs (Sambrook et al. 2001; Kato et al. 1999), socio-economic factors, various environmental perturbations, loss of habitat and overgrazing (Ashihara and Suzuki 2004; Kolosova et al. 2001). Therefore, immediate measures are needed to initiate conservation policies for this species in the northwest Himalaya.

Acidity in pH has also been reported by Sundriyal and Joshi (1990), Singh (1991) and Nautiyal (1996) in the alpine pastures of Garhwal Himalaya. Correlation matrices of different soil parameters at 0–10 cm depth with density are presented in Table 5. Variations reveal (Fig. 3A) highly significant correlation for pH ( $y = 0.0138x + 5.0436, R^2 = 0.104$ ), OC ( $y = -0.0095x + 1.8321, R^2 = 0.0126$ ), SOM ( $y = -0.0159x + 3.1553, R^2 = 0.0119$ ), TN ( $y = 0.0041x + 0.9007, R^2 = 0.0192$ ), EK ( $y = 0.0008x + 0.0541, R^2 = 0.144$ ) and AP ( $y = -0.0001x + 0.0231, R^2 = 0.0378$ ). Correlation matrices of different soil parameters at 10–20 cm depth with density are presented in Table 5. Variations reveal as follows (Fig. 3B): pH ( $y = -0.0308x + 4.9241, R^2 = 0.2726$ ), OC ( $y = 0.0012x + 1.0056, R^2 = 0.0023$ ), SOM ( $y = 0.0024x + 1.7294, R^2 = 0.0033$ ), TN ( $y = 0.0044x + 0.4702, R^2 = 0.0367$ ), EK ( $y = 0.0014x + 0.0512, R^2 = 0.3022$ ) and AP ( $y = 0.0002x + 0.019, R^2 = 0.038$ ). Plants in alpine zones are susceptible to environmental stresses (Korner 1999). Morphological variations and presence of secondary metabolites along with genetic diversity must be considered during the domestication of these plants. A germplasm collection (seeds and plant stock of all these populations) was underway at the time of this writing as were observations of phenotypic plasticity in our alpine garden and studies on genetic diversity. Future conservation strategies and cultivation of wild medicinal and other economically important species will be initiated on the basis of this array of information (Airi et al. 2000).

## Conclusions

These observations on threat status, population structure and nutrient profile of natural habitat of *A. balfourii* reveals that this species is restricted to specific pockets in wild and endangered in status. If the urgent steps for conservation are not taken, *A. balfourii* will be critically endangered in near future. On the basis of these observations of occurrence, availability, identification of potential habitat for collecting and multiplying germplasm for future domestication and cultivation, *A. balfourii* can be recognized and gainfully adopted for conservation.

*A. balfourii* will be critically endangered in near future. On the basis of these observations of occurrence, availability, identification of potential habitat for collecting and multiplying germplasm for future domestication and cultivation, *A. balfourii* can be recognized and gainfully adopted for conservation.



**Fig. 3 Correlation of density with various soil parameters: A (0–10 cm) and B (10–20 cm) depth.**

**Table 5. Correlation matrices of different soil parameters at different depths with density**

0–10 cm							
	Density	pH	OC%	SOM %	TN %	EK%	AP%
Density	1						
pH	0.322452	1					
OC%	-0.11214	-0.19885	1				
SOM %	-0.10908	-0.19836	0.99997	1			
TN %	0.138484	0.241457	0.279228	0.280921	1		
EK%	0.379506	0.112213	0.034744	0.031617	0.238407	1	
AP%	-0.19441	0.018273	0.05847	0.057604	-0.00255	-0.18198	1
10–20 cm							
	Density	pH	OC%	SOM %	TN %	EK%	AP%
Density	1						
pH	-0.52208	1					
OC%	0.047541	-0.06504	1				
SOM %	0.057131	-0.06975	0.999699	1			
TN %	0.191515	0.060196	0.407587	0.399655	1		
EK%	0.549694	-0.46042	-0.08837	-0.09157	-0.01274	1	
AP%	0.195005	0.043986	0.086791	0.094968	-0.31999	-0.14146	1

## Acknowledgements

The authors are grateful to Prof. A. R. Nautiyal, Director, for providing facilities. Assistance and opportune helping furnish from Mr. Sunesh Kumar Sharma, Department of Geography, Mr.

Arvind Badoni, Abhinendra Singh and Durga Prasad Gairola is also accredited. Financial support from the National Medicinal plant Board Govt. of India, New Delhi is gratefully acknowledged.

## References

Airi S, Rawal RS, Dhar U, Purohit AN. 2000. Assessment of availability and habitat preference of *Jatamansi* - a critically endangered medicinal plant of west Himalaya. *Current Science*, **79**(10): 1467–1470.

Allen SE. 1974. Chemical Analysis of Ecological Material. Oxford: Blackwell Scientific Publications, p. 565.

Anil, VS, Harmon AC, Rao SK. 2000. Spatio-temporal accumulation and activity of calcium-dependent protein kinases during embryogenesis, seed development, and germination in sandal-wood. *Plant Physiol*, **122**: 1035–1041.

Anon A. 1985. The wealth of India. A dictionary of Indian raw materials and industrial products. Vol 1: A. New Delhi: Publication and Information Directorate Council of Scientific and Industrial Research, p. 59.

Ashihara H, Suzuki T. 2004. Distribution and biosynthesis of caffeine in plants. *Front Biosci*, **9**: 1864–1876.

Bahuguna R, Purohit MC, Rawat MSM, Purohit AN. 2000. Qualitative and quantitative variations in alkaloids of *Aconitum* species from Garhwal Himalaya. *J Plant Bio*, **27**(2): 179–183.

Chakravarty HL, Chakravarti D. 1954. Indian aconites. *Eco Bot*, **8**: 366–376.

Gaur RD. 1999. Flora of the district Garhwal North West Himalaya (with ethnobotanical notes). Srinagar Garhwal: Transmedia, p. 65.

Goel PK, Trivedi RK. 1992. *Chemical and Biological methods for water pollution, soil and plant analysis* (1<sup>st</sup> Ed). Karad: Env. Publications.

Gordon JE, Newton AC. 2006. Efficient floristic inventory for the assessment of tropical tree diversity: a comparative test of four alternative approaches. *For Ecol Manage*, **237**: 564–573.

IUCN. 2001. The IUCN red list of threatened species. Categories and Criteria (version 3.1).

Jackson ML. 1958. Soil Chemical Analysis. New Jersey: Prentice Hall, p. 498.

Kato M, Mizuno K, Fujimura T, Iwama M, Irie M, Crozier A, Ashihara H. 1999. Purification and characterization of caffeine synthase from tea leaves. *Plant Physiol*, **120**: 579–586.

Kirtikar KR, Basu BD. 1935. Indian medicinal plants. Dehradun: Bishen Singh Mahendra Pal Singh (Rep.), **1**: 26.

Kolosova N, Sherman D, Karlson D, Dudareva N. 2001. Biosynthesis of the volatile ester methylbenzoate in snapdragon flowers. *Plant physiol*, **126**: 956–964.

Korner C. 1999. Alpine plants: stressed or Adapted?. In: MC. Press, JD. Scholes, MG. Barker (eds), *Physiological Plant Ecology*. Oxford: Blackwell Science Ltd., pp. 297–311.

Michael P. 1990. Ecological methods for field and laboratory investigations. New Delhi: Tata McGraw-Hill publishing Company Ltd..

Mishra R. 1968. *Ecology field book*. Oxford: Oxford and IBH Publications Co..

Naithani BD. 1984. *Flora of India: Flora of Chamoli* Vol I. Howrah: Botanical survey of India, Dept. of Environment, p. 26.

Nautiyal BP, Vinay Prakash, Bahuguna R, Maithani U, Bisht H, Nautiyal MC. 2002. Population study for monitoring the status of rarity of three aconites. *Tropical Ecology*, **43**(2): 297–303.

Nautiyal BP. 1996. Studies on structure and function in an alpine meadow of Garhwal, Central Himalaya. Srinagar Garhwal: Ph.D. Thesis submitted to H.N.B. Garhwal University, Srinagar Garhwal.

Odum EP. 2005. *Ecology*. New York: Holt, Reinhart and Winston (Reprint).

Okalebo JR, Gathua KW, Woomer PL. 1993. Laboratory methods of soil and plant analysis: a working manual. Kenya: TSBF Programme, UNESCO-ROSTA, pp. 22–29.

Olsen SR, Cole CV, Watanabe FS, Dean LA. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. Washington DC: US Government Print Office.

Padalia H, Chauhan N, Porwal MC, Roy PS. 2004. Phytosociological observations on tree species diversity of Andaman Island, India. *Current Science*, **87**: 799–806.

Parthasarathy N. 1999. Tree diversity and distribution in undisturbed and human-impacted sites of tropical wet evergreen forest in southern Western Ghats, India. *Biodivers Conserv*, **8**: 1365–1381.

Rawat N. 2009. Assessment of productivity, rate of decomposition and nutrient cycling of an alpine grazing land in Western Himalaya. Ph.D. thesis H.N.B. Garhwal University, Srinagar Garhwal.

Rikhari HC, Negi GCS, Singh SP. 1993. Species and community diversity patterns in an alpine meadow of central Himalaya. In: U. Dhar (ed.), *Himalayan Biodiversity: Conservation strategies*. GBPIHED. Kosi Katarmal (Almora), pp. 205–218.

Sambrook J, Fritsch EF, Maniatis T. 2001. *Molecular cloning. a laboratory manual*. New York, Cold Spring Harbor: Cold Spring Harbor Laboratory Press.

Semwal S. 2006. Studies on phytosociology, diversity patterns and competition along an altitudinal gradient in a part of Lesser Himalaya in Garhwal, Uttarakhand. Ph.D. thesis H.N.B. Garhwal University, Srinagar Garhwal.

Sheldon JW, Balick MJ, Laird SA. 1997. Medicinal plants: can utilization and conservation coexist? *Advances in Economic Botany*, **12**: 1–104.

Singh SP. 1991. Structure and function of low and high altitude grazingland ecosystems and the impact of the livestock component in the Central Himalaya. Final Technical Report. D. O. En., Government of India, New Delhi. Species in Garhwal Himalaya..

Stapf O. 1905. *The Aconites of India: A Monograph*. Calcutta: Bengal Secretariat Press, p. 160.

Sundriyal RC, Joshi AP. 1990. Effect of grazing on standing crop, productivity and efficiency of energy capture in an alpine grassland ecosystem at Tungnath (Garhwal Himalaya). *Indian Trop Ecol*, **31**: 84–97.

Sundriyal RC, Joshi AP. 1991. Annual nutrient budget for an alpine grassland in the Garhwal Himalaya. *Journal of Vegetation Science*, **3**(1): 21–26.

Ved DK, Kinhal GA, K. Ravikumar, Prabhakaran V, Ghate U, Sankar RV, Indresha JH. 2003. CAMP report: conservation assessment and management prioritisation for the medicinal plants of Jammu & Kashmir, Himachal Pradesh & Uttarakhand, Workshop, Shimla, Himachal Pradesh. Bangalore: FRLHT, p. 206.

Verma RK, Kapoor KS, Subramani SP, Rawat RS. 2004. Evaluation of plant diversity and soil quality under plantation raised in surface mined areas. *Indian Journal of Forestry*, **27**(2): 227–233.

Walkley A, Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, **34**: 29–38.

Whittaker, R. H. 1972. Evolution and measurement of species diversity. *Taxon*, **21**: 213–251.

Wilson MV, Shmida A. 1984. Measuring  $\beta$ -diversity with presence - absence data. *Journal of Ecology*, **72**: 1055–1064.